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CHANGE OF FORM AFFECTING A MAGNETIC FIELD.[1]

HITHERTO the study of a magnetic field has been the study of the so-called lines of force radiating from the poles of magnets, either electro or permanent; and, so far as magnetism has been utilized in the arts, the changes in this external field have been brought about by the movements of an armature, having for its function to determine the direction and consequent density of the field. Such is the case in the instruments used in the telegraph, the telephone, in dynamos, and in motors. Sometimes conducting wires are so mounted in the field that their movement gives rise to electric currents, which signifies that the energy producing the tension in the field is absorbed in some measure by the moving wires, and is transformed into an electric current. In each of these cases the magnet producing the field is stationary; that is, changes in the magnetic field produced by it are due to a motion external to the magnet itself, and may be that of an armature, of a moving wire, or of its own bodily change of position,— a kind which is comparable with what is called external motion in thermo dynamics, to distinguish it from internal motions, or such as take place when the body changes its form. So far as I am aware, no study has been made of the effect of changing the form of a magnetic body on its field, or of the reaction upon itself of its magnetic condition due to a periodic change of form. Of course, it has been known for a long time that the form of the magnetic field depended upon the form of the magnet itself. For a straight bar magnet, this field is familiarly known by the arrangement of iron filings forming curved lines from each pole re-entering the opposite pole. When the iron is bent into a U-form, or horseshoe magnet, the field is mostly contracted to the space between the poles. These forms of magnets have been permanent ones for the purpose for which the magnet was made.

In the case of induction-coils, whether of one form or another, the magnetic change produced by it has been and is due to the electric change produced upon it by an electric circuit provided with intermittent or alternating currents.

Within a few years, attention has been called to the nature of the external field as being a part of what is now known as the magnetic circuit, which consists of these rings or closed circuits of lines of force, all originating in the iron part of the circuit, and for conducting which iron is by far the best. The poles of the magnet are simply the parts of the iron where the lines enter and leave, and they may be in any place. Usually they are at the ends of the iron, but not necessarily so. Whenever iron is placed in the magnetic field, these lines crowd into it, as it is a much better conductor than the ether. When the iron is made into a ring form and then magnetized, there is no external polarity, and consequently no external field, provided that the iron has sufficient conducting cross-section at every part.

The following experiments have been tried, to determine what effects, if any, are produced upon a magnetic field by changing the form of the magnet. It was thought at first, that if a helix was coiled into a circle and a current was present in it, changes in its form would produce corresponding changes in the magnetic field external to the coil, especially noticeable if a flexible iron ring was enclosed in the helix so as to condense the magnetic field. This was put to the test in the following manner.

I. A coil similar to the one described above, but containing a solid ring of iron about eight inches in diameter and an inch thick, had its coil put in circuit with a reflecting galvanometer of low resistance, and at such a distance from it that magnetic fields external to its circuit could not act upon it. Another coil made about a flexible ring of iron wire was put in circuit with a battery, so as to magnetize the ring strongly. Then, with one ring parallel to the other, the flexible one was made suddenly to assume an elliptical form. Each such change in form, from one ellipse to another at right angles to it, gave a deflection of the needle to the right or left, and uniformly for a given phase of change. It was also observed that the direction of the deflection was reversed when the flexible ring was turned the other side up.

II. The same flexible ring, used in the same way, but without the current through it, gave substantially the same results. Of course, the ring was permanently magnetized, and the change might have been inferred.

III. As the same kind of motion, due to change of form, is taking place when a ring is vibrating at its harmonic rate, producing what we call sound-vibrations, it was thought probable that a magnetized ring, having a coil of wire about it in connection with a telephone, would set up vibratory currents when it was struck; and this was found to be true, for, when the coil containing the heavy iron core was put in circuit with a telephone in another room, the sound of the stroke and the pitch of the ring could plainly be heard. In the first case, the number of turns of wire was small, perhaps fifty or thereabouts. I therefore had two larger rings made, each about one foot in diameter and half an inch thick.

IV. One of these was wound with six or seven hundred turns of No. 32 wire. Before it was magnetized, it was connected with the telephone, and tested for its magnetic condition by striking. The ring could plainly be heard, which showed that it had some degree of magnetism.

V. Then about two hundred turns of coarse wire were wound upon it, and a strong current sent through it to magnetize it. After this magnetizing coil had been removed, the ring was again tested as in IV. The sound was very much louder. Indeed, the telephone could be held a foot from the ear and be heard.

VI. With the ring in V. still in circuit, the companion ring, without any wire upon it, was brought near it and struck. The sound was easily heard in the telephone circuit.

VII. This second ring was now magnetized in the same way as the first, when the magnetizing helix was removed, and experiment VI. repeated. The sound was very much louder.

VIII. The ring was now struck and moved away from the first ring by stages of an inch or two at a time. It was found possible to hear its pitch in the second circuit, when it was a yard or more away from it.

IX As the pitch of the two rings was not quite the same, the higher one was loaded so as to bring them to unison. The sound was then louder and more persistent than before. This gave evidence that it was a case of sympathetic vibration, while the former were forced vibrations.

[1] Paper presented Jan. 14, 1891, by A. Emerson Dolbear, to the American Academy of Arts and Sciences, Boston.

X. A common horseshoe permanent magnet, with legs about six inches long, had perhaps fifty ohms of No. 32 wire wound about the bend, and this was put in circuit with the telephone, and struck like a tuning-fork. The sound in the telephone was very loud; indeed, too strong to be held comfortably at the ear.

XI. A coil of wire was now put about the middle of a piece of gas-pipe, which was without permanent magnetism. The piece of pipe was about four feet long and five eighths of an inch in diameter. This, when in connection with the telephone, was struck two or three times a second with a piece of brass rod, and while being thus struck it was rotated from the magnetic meridian to a position at right angles to it. The difference in the loudness of the sound, between the position in the meridian and away from it, was very marked. It is therefore shown to be possible to determine the points of the compass with a telephone, a coil, and an iron rod.

XII. A second flexible ring was now made, about a foot in diameter, consisting of a bundle of soft iron wire, the ends being roughly braided and twisted together. The thickness of this was rather less than half an inch. This was covered by a rubber tape wound spirally round it, the better to secure stability of form and insulation. Then 4.6 ohms of No. 21 wire were wound about it its entire length, making probably a thousand turns. It was then magnetized by a current from three secondary cells having six volts, giving a magnetizing current of about thirteen hundred ampère turns, leaving it a ring magnet. The terminals were then connected with the terminals of a reflecting galvanometer with a resistance of .67 of an ohm. Very slight changes in the form of the ring, either by pulling or pushing, gave decided movements to the needle, while larger amplitude gave thirty to forty degrees' deflection.

XIII. It was noticed, also, that the direction of the current depended not only upon the direction of the motion of changing the form, but also upon the direction of the motion with reference to the normal shape of the ring. Thus, if the ring be a circle, and it be drawn into a horizontal ellipse, the current will move the galvanometer-needle, say, to the right. When it is brought back to the circular form, the current is reversed. If the motion be continued so as to produce a vertical ellipse, the current will be in the same direction as that produced at first by a motion exactly opposite in direction; so that for a complete cycle of vibratory changes four currents are generated,— two direct, and two reverse.

XIV. One of the iron rings before mentioned, a heavy one about eight inches in diameter and an inch and a half thick, having coarse wire wound upon it nearly covering the ring, was connected with the galvanometer as before, and the ring was struck by a brass rod. The needle instantly swung through a wide angle. Struck again, it moved as before, but not through so wide an angle, and a half-dozen blows knocked nearly all the magnetism out of the ring. This was then detached from the galvanometer and magnetized, as before, when it again gave the same large deflection it gave at first. The same conditions were tried with other rings, and in each case it was found that a vigorous stroke upon the ring magnet had the same destroying effect upon the magnetism as it has upon magnets having external fields.

XV. The flexible ring was now put in circuit again, and vigorously jerked with the hands. A very few such movements served to destroy nearly all the magnetism present, requiring the remagnetization of the ring.

As flexible iron rings such as I wanted were not easy to make, I procured some steel wire rope of the right size, and the ends were welded for me through the courtesy of Professor Elihu Thompson of Lynn by his electrical welding process. Such a ring about a foot in diameter allows a movement of five or six inches to one of its sides. This, when wound with four or five hundred turns of No. 22 wire, may be magnetically saturated by sending a current through the wire, leaving the ring charged. The terminals may now be connected with a proper galvanometer, and changes in the form will discharge the ring.

These experiments prove, —

1. That a change in the form of a magnet causes corresponding change of stress in the field.

2. That periodic changes in form due to elasticity of form, such as are called sound-vibrations, set up similar periodic changes or waves in the magnetic field.

3. That such sound-vibrations of a magnet act upon other magnets like sound-vibrations, and set them into corresponding vibratory movements, sympathetic or forced, — sympathetic when the receiving magnet has the same pitch as the transmitting magnet, and forced when it has not the same pitch.

4. That such sound-vibrations in the receiving-magnet cause a corresponding change of form in its magnetic field, which manifests itself by electric currents in circuits surrounding it.

Sir William Thomson has frequently said that he could understand a mechanical idea when he could make a model of it, but could not otherwise. If one assumes that the ultimate atoms of iron are magnets, as is thought most probable now, or holds, by Ampère's hypothesis, that currents of electricity circulate about each atom, making it a magnet — in either case, each individual atom has its own magnetic field, which is necessarily always with it. It is really its re-action upon the ether. If such atoms be elastic, as there is the best of reasons for believing, then it follows that impact must set them into periodic vibratory motion; that is, periodic change of form at a rate depending upon its degree of density and elasticity. Such changes of form set up corresponding periodic waves in the ether, as changes in the magnetic field; and these are transmitted outwards with a rate depending upon the properties of the ether to transmit such motions, not upon the source of the disturbance.

Such vibratory motions among atoms and molecules we call heat, and such periodic waves in the ether we call light, and thus Maxwell's idea of light being an electro magnetic phenomenon is altogether in accordance with the experiments. For waves of the lengths of light waves, it is essential that the vibrating body be small and highly elastic. Maxwell's idea was, that the opposite phases of ether-waves could produce opposite electrical effects, so that each half-vibration represented either positive or negative conditions; and these implied, though I have not noticed the statement, that they must have originated with vibrating magnetic atoms or molecules. It has been difficult or impossible heretofore to imagine how ether-waves could be set up by vibrations of the elements, though the idea that the atoms of matter are magnets is not new at all, and has a good degree of probability.

If one is to picture to himself at all how this kind of a phenomenon can occur, he is bound to have in mind some form for an atom that shall at the same time be a consistent magnetic form. If atoms are magnets, it is well-nigh inconceivable that they should be spheres or cubes, or tetrahedra, or disks, or any of the ordinary geometric forms, for such would be very poor forms to exhibit magnetic properties. But a ring presents a very different case, as a ring magnet is the most perfect form possible. There is this to be said of such a form, however. It does not present what we commonly call a magnetic field: it is a closed circuit.

Nevertheless, I would ask if it is probable that the ether external to a magnet of that form should be quite unaffected, quite neutral. I should suppose not, but, on the contrary, should look for some sort of stress there, though it might be of somewhat different nature, and have somewhat different properties, from an ordinary magnetic field. But if such were the case, it follows that any magnetic change in the ring magnet itself would be followed by a corresponding change in the external field, and vibratory motions would necessarily set up waves in that field. Such waves would have a magnetic origin, but the waves themselves would not necessarily give rise to electro-magnetic effects directly. Indirectly they would; for, if they could make another similar magnet vibrate sympathetically, these vibrations would re-act upon its magnetic properties.

Such a ring form as I have shown suggests at once the vortex ring theory of atoms, of the properties of which I have so often spoken to the academy. Perhaps the experiments should have a different interpretation from that suggested here; but, whatever their interpretation may be, they are believed to be entirely new, and therefore of interest, if not important.